Geoacoustic Inversion in Shallow Water

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LONG TERM GOALS

The ability to predict transmission loss of sound propagating in shallow water is constrained by the knowledge of the geoacoustic properties of the bottom. The long term objectives of this research project are related to the investigation of experimental methods and inversion techniques for estimating parameters of geoacoustic models of the ocean bottom and the associated uncertainties in the model parameter values. The specific goals are to evaluate the performance of geoacoustic inversion techniques that have been developed for use in range-dependent shallow water environments, and synthesize the results obtained for characterizing the seabed from the SW06 and other recent experiments. The wider context of this research is to achieve improved sonar system performance through greater understanding of the physics of the interaction of sound with the ocean bottom.

OBJECTIVES

The experiments carried out in the ONR SW06 Experiment during August-September 2006 on the New Jersey continental shelf provided high quality data over a broad frequency band from 50 Hz to 20 kHz that can be used for evaluating and comparing the performance of several different techniques. These include matched field inversion, reflection coefficient and bottom loss inversion, phase and group velocity dispersion and wavenumber extraction inversions. This report presents comparisons of results from the different experiments and compares the performance of geoacoustic inversion methods that were used to estimate parameters of geoacoustic profiles in SW06. Evaluation of the estimated geoacoustic profiles against suitable metrics will determine whether the SW06 experiments can serve as an experimental benchmark for the inversion methods.

A critical issue in the many of the inversion methods is the impact of uncertainty in the knowledge of the ocean environment and the experimental geometry on inversion performance. An objective in this work is to investigate approaches for estimating geoacoustic model parameters that are robust to environmental and experimental uncertainty.

APPROACH

The research makes use of data recorded from different experiments in the vicinity of the MORAY site (Yang et al, 2008). This area of outer shelf wedge sediments (Figure 1) was intensively surveyed with

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chirp sonar, in situ seabed physical property measurements and grab samples. Two hydrophone arrays were deployed at the site, first the MORAY system from the Applied Physical Laboratory (APL), and subsequently at the end of SW06 a Marine Physical Laboratory (MPL) vertical array (VLA1), so that there are data covering the full frequency band. Also the Woods Hole SHARK vertical array was deployed nearby. The experiments were carried out at close ranges (< 200 m) from the arrays, and along the track shown in the figure out to about 8 km.

The high resolution chirp sonar surveys revealed well-resolved structure down to about 30 m, most prominently the 'R' reflector at about 20 m (Goff et al, 2004). This interface, which is pervasive in the region, was overlayed with alternating layers of sand and finer clay. The preliminary analysis of the situ sediment probe data indicated a sound speed value of around 1620 m/s for the sea floor sediments near VLA1 (Yang et al, 2008).

The approach described here makes a comparison of the estimates of geoacoustic properties from the different experiments in relationship to the ground truth information. Following this, the geoacoustic profiles derived from the inversion experiments will be evaluated against a suitable metric such as experimentally determined transmission loss versus range, coherence or possibly the Bartlett power versus depth at specific ranges.
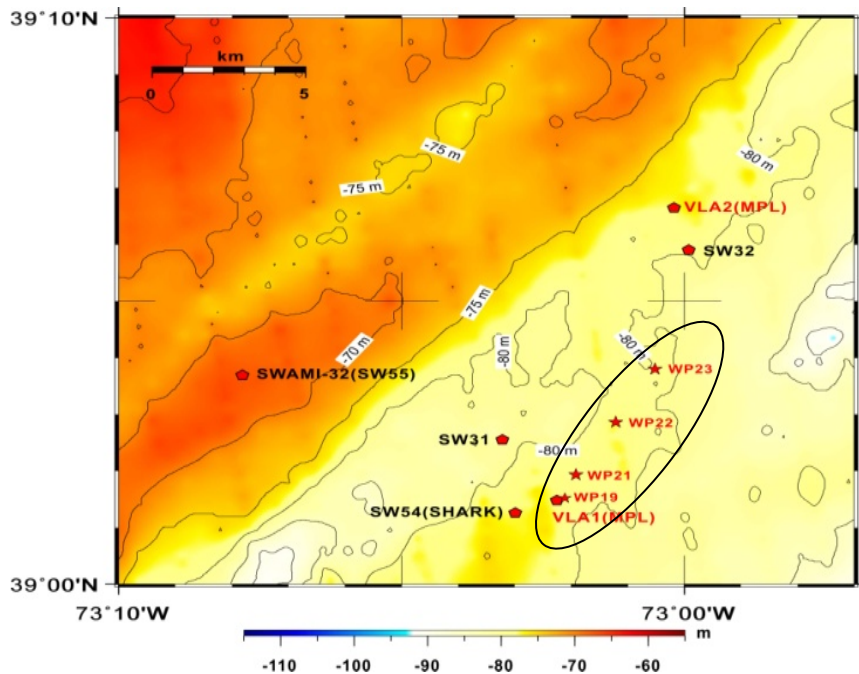

Figure 1. Location of the experiments on the New Jersey Shelf.

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WORK COMPLETED

The initial stage of the inversion methods comparison was completed to collect and compare the results of different inversion techniques against ground truth information. Comparisons are shown here for inversions of sediment sound speed and attenuation to assess the consistency of the results from different techniques.

A technique that shows considerable promise for robust inversion with limited knowledge of the experimental environment is time-frequency warping. This method was implemented and tested using light bulb data recorded on the MPL vertical array.

RESULTS

Comparison of the sea floor sediment sound speed estimates that have been reported is shown in Figure 2. The in situ ground truth measurements (APL: SAMS (Yang et al, 2008) and NRL: GeoProbe) are in close agreement with the matched field inversion (MFI) results (University of Victoria (UVic) and MPL (Jiang et al, 2008)). The very low frequency data inversions (50 Hz) likely sample the higher sound speeds at deeper depths below the 'R' reflector. The high frequency estimates (APL (Choi et al, 2008)) are localized close to the array, and may reflect the sound speed in high speed sand layers within 1 m of the sea floor (Mayer et al, 2002).
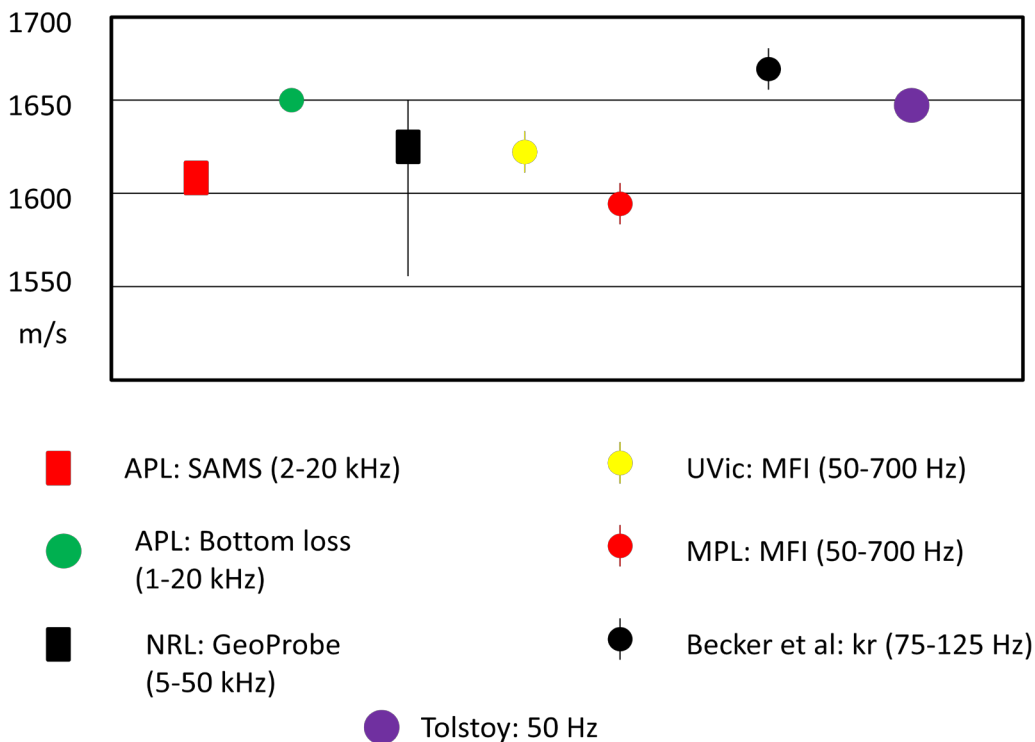

Figure 2. Comparison of sea floor sound speed estimates.

Comparisons were also made for geoacoustic profiles to depths of the 'R' reflector (Figure 3). As a measure of the uncertainty, the marginal distributions from the UVic Bayesian inversions are about ± 15 m/s. This indicates that the MFI, travel time and waveform inversions based on LF and MF data are very close. Also, from Figure 2, the high frequency in situ measurements that are characteristic of the sea floor sediments are about the same values. This result indicates a relatively slow variation of sound speed with depth. The University of Rhode Island (URI) modal dispersion estimates were based on data from a track that traversed outer shelf wedge sediments and higher speed sandy sediments closer to the coast. The results from Becker et al. (Ballard and Becker, 2010) are from a linearized perturbation inversion that provides a range-dependent geoacoustic profile over the experimental track. However, the method requires prior information about the travel time to sub-bottom interfaces from the chirp sonar data.
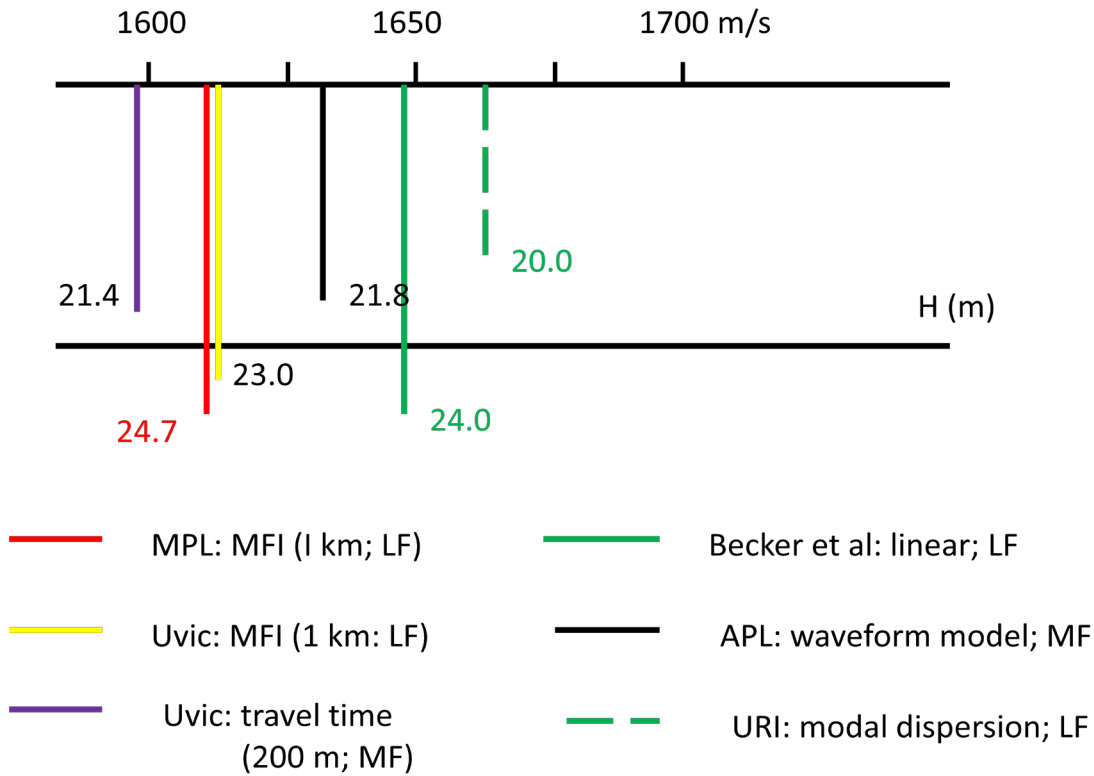

Figure 3. Comparison of average sound speed estimates. The depth to the 'R' reflector is shown (in m) for each inversion method.

The comparison of estimated values of sediment sound attenuation is shown in Table 1. These results indicate generally a lower attenuation for the outer shelf wedge sediments compared to the higher attenuation reported by Zhou (2009) for the sandy sediments in most of the New Jersey shelf. The higher frequency results also suggest a linear dependence on frequency above about 2 kHz. This result generally unexpected from predictions based on Biot theory of sound propagation in porous sediments. The analysis indicates poor consistency among the low frequency results from the two techniques. The

URI estimates are based on modal amplitude ratios at long ranges that relies on adequate resolution of the modes. This method is being investigated in relationship to the time-frequency warping method to take advantage of the improved resolution provided by this technique.

Table 1. Low- and mid-frequency attenuation estimates.

Method	Frequency Band	Value: dB/m/kHz
Uvic: MFI (CW) long range ~ 5 km	50-700 Hz	a = 0.14 B = 1.3
Uvic: VLA (spectral ratio) short range ~ 200 m	1.75-3.15 kHz	0.1 (linear)
URI: modal amplitude ratio (22 km)	< 100 Hz	a = ? B = 1.87
NRL: Chirp sonar (spectral ratio)	5-8 kHz	0.12 (linear)
NRL: Geoprobe	5-50 kHz	0.1-0.4
APL: waveform modeling	2 kHz	0.05

Initial results with the time-frequency warping method were reported for estimation of sediment sound speed and density from light bulb data recorded on the MPL array (Bonnel and Chapman, 2011). The significant advantages of this technique are the improved modal resolution at relatively short ranges and the insensitivity to uncertainty in knowledge of the experimental environment. Sediment sound speed estimated from a light bulb implosion at ~ 7 km (1600 m/s) was consistent with the values shown in Figures 2 and 3. Additionally, the density is also obtained in the inversion.

IMPACT/APPLICATIONS/TRANSITIONS

The assessment of performance of the inversion techniques will provide new information about the limitations and advantages of the different methods.

RELATED RESEARCH

The data from the SW06 experiments are high quality data that can serve as benchmark standards for evaluating the performance of geoacoustic inversion methods to provide new understanding of the strengths and limitations of present day inversion techniques. The knowledge gained in this work will

identify gaps in our understanding that can be addressed in designing the next phase of experiments. The research is connected with research projects of the following: W. S. Hodgkiss and P. Gerstoft (MPL, SCRIPPS); D. Knobles (ARL:UT); G.V. Frisk (Florida Atlantic); K. Becker (ARL Penn State); P. Dahl and D.J. Tang (APL UW); J. Miller (University of Rhode Island), J. Goff, U of Texas at Austin and J. Lynch (WHOI). The overall goal of this group is to characterize the geoacoustic environment and understand mechanisms of the interaction of sound with the ocean bottom.

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